Morphometric Analysis of the Mandible in Subjects with Class III Malocclusion

Jin-Yun Pan,[1] Szu-Ting Chou,[1] Hong-Po Chang,[1,2] and Pao-Hsin Liu[3]
[1]Department of Orthodontics, Kaohsiung Medical University Hospital,
[2]Faculty of Dentistry, College of Dental Medicine, Kaohsiung Medical University, Kaohsiung, and
[3]Institute of Biomedical Engineering, National Cheng Kung University, Tainan, Taiwan.

This study evaluated the deformations that contribute to Class III mandibular configuration, employing geometric morphometric analysis. Lateral cephalograms of male and female groups of 100 young adults and 70 children with Class III malocclusion were compared to those of counterparts with normal occlusion. The sample included an equal number of both genders. The cephalographs were traced, and 12 homologous landmarks were identified and digitized. Average mandibular geometries were generated by means of Procrustes analysis. Thin-plate spline analysis was then applied to mandibular configurations to determine local form differences in male and female groups of adults and children with normal occlusion and Class III malocclusion. The mandibular morphology was significantly different between these two groups of male and female adults, and children ($p < 0.0001$). This spline analysis revealed an anteroposterior elongation of the mandible along the condylion–gnathion axis, showing an extension in the regions of the mandibular condyle and ramus, and of the anteroinferior portion of the mandibular symphysis in Class III groups. More extension was evident in Class III adults. The deformations in subjects with Class III malocclusion may represent a developmental elongation of the mandible anteroposteriorly, which leads to the appearance of a prognathic mandibular profile.

Key Words: adults, children, Class III malocclusion, mandible, morphometric analysis
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Class III malocclusion is generally a skeletal type of occlusal variation [1], and treatment of a skeletal Class III condition in growing children remains one of the most challenging problems confronting the practicing orthodontist. Class III problems are more common in Asian populations or in those of Mongoloid descent [2–6].

Conventional cephalometry, based on angular and linear measurements, has proved to be insufficient for the analysis of shape changes of complex anatomical forms such as the craniofacial complex [7–9]. The actual sites of putative craniofacial skeletal changes are insufficiently evidenced in traditional cephalometric analysis. Bookstein [10,11] introduced an effective morphometric method for shape comparisons called thin-plate spline (TPS) analysis. TPS graphical analysis facilitates the construction and display of transformation grids that capture the shape change between forms. A direct comparison of shapes will show where the differences are and by how much they differ. This conceptually simple maneuver rapidly shows the location and extent of the deformation.

This study provides more information about the morphologic differences in the mandible between Class III malocclusion and normal occlusion in adults and children. Geometric morphometric assessments were carried out to localize alterations, using Procrustes analysis and TPS analysis.

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Address correspondence and reprint requests to: Dr Hong-Po Chang, Department of Orthodontics, Kaohsiung Medical University Hospital, 100 Tzyou 1st Road, Kaohsiung 807, Taiwan.
E-mail: hopoch@kmu.edu.tw

Materials and Methods

Subjects

The first study sample comprised 200 young adults with ages ranging from 18 to 22 years. Male and female groups of 100 adults with pretreated Class III malocclusion (mean age: men, 20.49 ± 0.59 years; women, 20.59 ± 0.67 years) were compared to those of 100 adults with untreated normal occlusion (mean age: men, 20.55 ± 0.62 years; women, 20.60 ± 0.69 years). The sample included an equal number of both genders. The second sample comprised 140 children with ages ranging from 9 years 5 months to 11 years 4 months. Male and female groups of 70 children with pretreated Class III malocclusion (mean age: boys, 10.69 ± 0.69 years; girls, 10.50 ± 0.53 years) were compared with those of 70 children with untreated normal occlusion (mean age: boys, 10.56 ± 0.60 years; girls, 10.44 ± 0.53 years). The second sample also included an equal number of both genders. Radiographs were obtained from the files of records maintained at the Department of Orthodontics, Kaohsiung Medical University Hospital. The protocol was examined and approved by the hospital's institutional ethics committee.

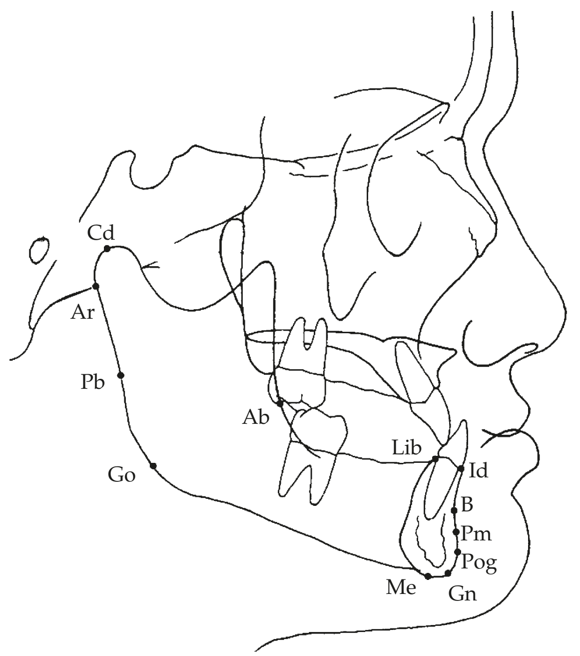

Figure 1. *Homologous mandibular landmarks used for the construction of a 12-noded geometry. Ab = anterior border of the ramus; Ar = articulare; B = B point; Cd = condylion; Gn = gnathion; Go = gonion; Id = infradentale; Me = menton; Lib = lower incisor lingual bony contact; Pb = posterior border of the ramus; Pm = protuberance menti; Pog = pogonion.*

The lateral cephalographs were traced by a single investigator. Twelve mandibular landmarks were identified and digitized (Figure 1). The software used in this study was written in the "MATALAB 5.3" (Version 2.3, CAESAR Lab, NCKU, Taiwan) and implemented on a 1.0-GHz Pentium III PC. In order to assess errors involved in cephalometric tracing and digitizing, 30 randomly selected lateral cephalographs were traced and digitized. The same cephalographs were then retraced and redigitized under the same conditions after an interval of 1 week. The method errors between the repeated measurements were then analyzed for both angular and linear measurements [12]. There were no significant differences between the two sets of repeated measurements. The method errors were between 0.16 and 0.29 mm for linear measurements and between 0.26 and 0.60 degrees for angular measurements, and the reliability coefficients [13] were from 0.97 to 1.00. These had been previously assessed [14].

Procrustes analysis

An average 12-noded geometry for each group was determined by generalized orthogonal Procrustes analysis [15,16]. According to this method, every object's coordinates were translated, rotated, and scaled iteratively until the least-square fit of all configurations could no longer be improved. Therefore, all configurations were registered with respect to one another; and as a result of this procedure, geometric mandibular configurations were scaled to equivalent areas, thus avoiding problems introduced by individual differences in size. The normal group mean geometry was compared statistically with the average geometry of the Class III group using an analysis of variance (ANOVA) [15–17].

TPS analysis

After the mean geometric configurations for each group were computed using Procrustes analysis, TPS analysis [10,11] was used to visualize major differences in the geometric configuration of the mandible between the normal occlusion and the Class III groups. The normal occlusion average was taken as the initial geometry and the Class III configuration was treated as the final geometry. TPS graphical analysis shows the shape difference or deformation, which appears as vertical compression/extension and/or horizontal compression/extension of the grids on the graphical displays when the initial and final lateral cephalographs are superimposed and the landmark configurations are compared. The total spline in TPS graphical analysis allows the visualization of the differences between two mean configurations as a transformation grid, whether these are statistically significant or not. To determine whether the two mean configurations are morphologically different, we should rely upon the residuals of homologous landmarks from Procrustes analysis using an ANOVA [15–17]. A more detailed review of the theoretical basis and calculation procedures of TPS morphometrics can be found in Bookstein [10,11], and Dryden and Mardia [18].

Results

Residuals and corresponding F values derived from Procrustes analysis indicated that the mean normal occlusion and Class III mandibular configurations for male and female groups of both adults and children differed significantly ($p < 0.0001$; Table). Statistically significant differences between normal occlusion and Class III comparisons enabled further TPS analysis.

The mean mandibular configurations of the male and female groups of normal occlusion adults revealed in untransformed space are shown in Figures 2A and 3A, respectively. The TPS graphical display of both male and female groups of Class III adults revealed an anteroposterior elongation of the mandible along the condylion–gnathion (Cd–Gn) axis, showing an evident extension in the regions of the mandibular condyle and ascending ramus, and of the anteroinferior portion of the mandibular symphysis (Figures 2B and 3B).

Figures 4A and 5A show the mean mandibular configurations in untransformed space for the male and female groups respectively of children with

Table. Procrustes analysis of mean mandibular configuration between normal occlusion and Class III malocclusion groups

	Residual ($\times 10^{-4}$)	F	p
Female adult	2.527	9.3473	<0.0001
Male adult	4.786	10.4484	<0.0001
Female child	3.914	4.4169	<0.0001
Male child	5.617	26.7095	<0.0001

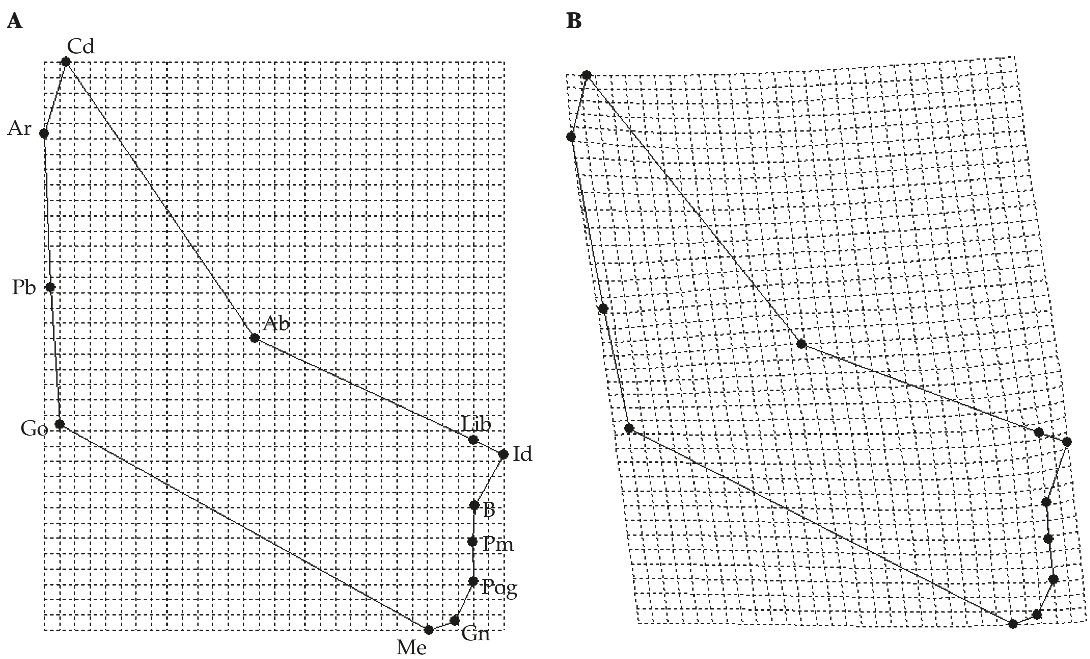

Figure 2. *Thin-plate spline (TPS) depiction of the mandibular configuration in a group of male adults. (A) Mean mandibular configuration of a group of male adult normal controls in untransformed space. (B) TPS graphical display showing mandibular shape changes as total spline in male Class III malocclusion adults.*

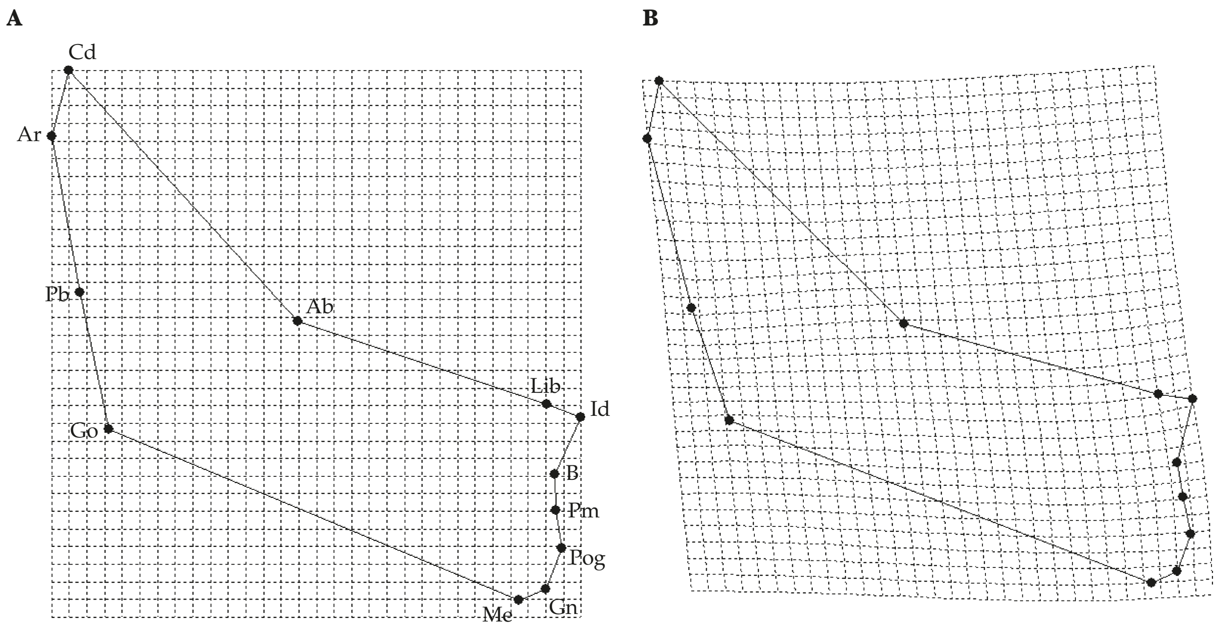

Figure 3. *Thin-plate spline (TPS) depiction of the mandibular configuration in a group of female adults. (A) Mean mandibular configuration of a group of female adult normal controls in untransformed space. (B) TPS graphical display showing mandibular shape changes as total spline in a group of female Class III malocclusion adults.*

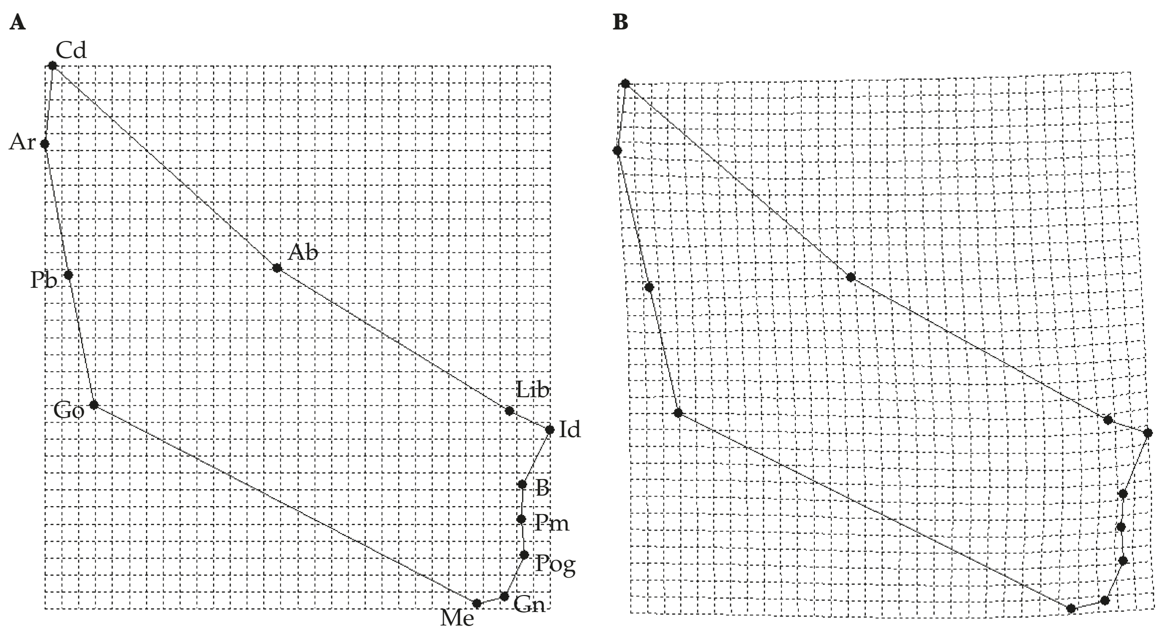

Figure 4. *Thin-plate spline (TPS) depiction of the mandibular configuration in a group of male children. (A) Mean mandibular configuration of a group of male child normal controls in untransformed space. (B) TPS graphical display showing mandibular shape changes as total spline in male Class III malocclusion children.*

normal occlusion. TPS mandibular analysis of the male and female Class III children revealed an anteroposterior elongation of the mandible along the Cd–Gn axis, showing an extension in the regions of the mandibular condyle and upper portion of the ramus, and of the anteroinferior portion of the mandibular symphysis (Figures 4B and 5B).

However, there were horizontal compressions between the anterior and posterior borders of the ascending ramus (Ab–Pb), and the mandibular

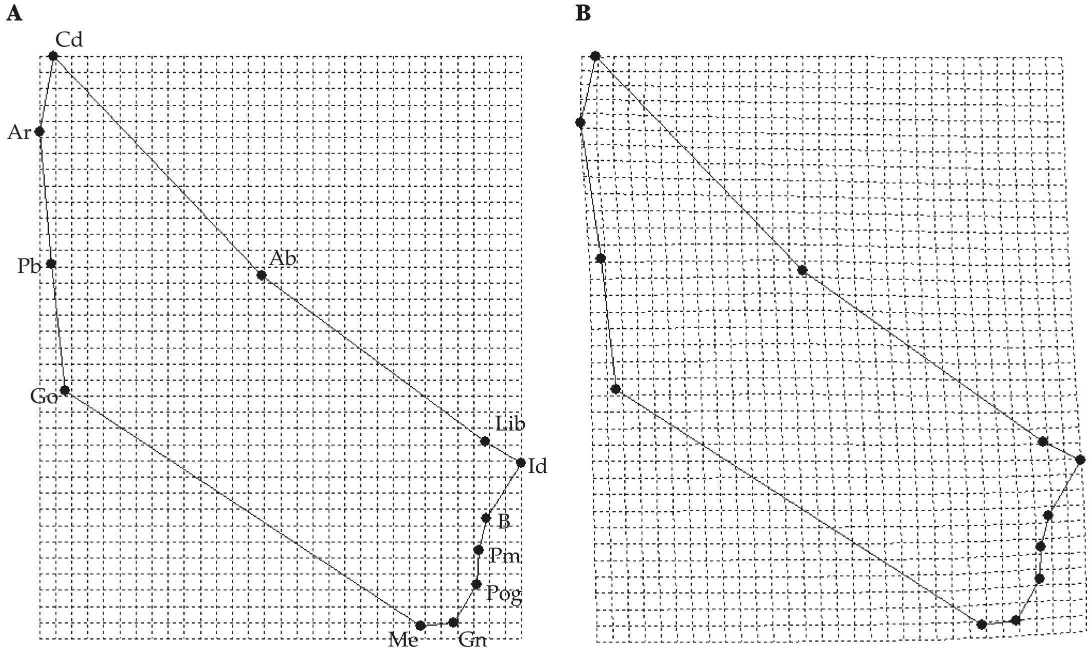

Figure 5. *Thin-plate spline (TPS) depiction of the mandibular configuration in a group of female children. (A) Mean mandibular configuration of a group of female child normal controls in untransformed space. (B) TPS graphical display showing mandibular shape changes as total spline in a group of female Class III malocclusion children.*

alveolus between the infradentale (Id) and lower incisor lingual bony contact point (Lib) in both male and female groups of Class III adults and children (Figures 2B, 3B, 4B, and 5B). Furthermore, analysis revealed vertical stretching of the dentoalveolar processes in both male and female groups of Class III adults and children (Figures 2B, 3B, 4B, and 5B).

Discussion

Typical Class III malocclusion is characterized by several craniofacial and developmental features, including a high mandibular plane angle, obtuse gonial angle, and an underdeveloped maxilla and/or overdeveloped mandible [4,19,20]. Mandibular prognathism or skeletal Class III malocclusion with a prognathic mandible has long been viewed as one of the most severe facial deformities [19,20]. The Class III subject undergoes changes in occlusal patterns because occlusal morphology is dictated by mandibular length and size [21]. As the Class III mandible grows more forward, it carries a longer part of the mandibular denture to a shorter diameter of the maxillary denture. Therefore, mandibular protrusion may be one feature responsible for Class III malocclusion [22] and this may be more evident in prognathic adults. The forward or counterclockwise rotation of the mandibular ramus and downward or clockwise rotation of the mandibular plane increased in a more obtuse gonial angle as revealed by the transformation grids. The more obtuse gonial angle contributed to a relatively greater total mandibular length in Class III groups. In the present study, the mandibular morphology was significantly different in Class III subjects compared to normal controls. The changes in mandibular morphology noted for Class III malocclusion may represent a developmental elongation of the mandible anteroposteriorly, leading to the appearance of a prognathic profile.

In Class III groups, the ramus is horizontally narrow, as revealed by horizontal compressions between its anterior and posterior borders in the transformation grids and it thereby reduces the extent of, and partially compensates for, mandibular protrusion. Thus, the narrower ramus is a key anatomic compensatory feature that effectively reduces the frequency and severity of Class III malocclusion [23]. Enlow [1] pointed out that the narrow ramus is often an effective feature that minimizes the Class III malocclusion in Asians.

Dentoalveolar compensation is characteristic of skeletal Class III malocclusion. In prognathic subjects, dentoalveolar compensation is common in both maxillary and mandibular arches. Compensating for the intermaxillary skeletal discrepancy during mandibular protrusion in the prognathic sample, examples by the lower incisor with lower alveolar process were tipping lingually, as revealed by horizontal compression and vertical stretching of the dentoalveolar process in the transformation grids. The lower incisor and lower alveolar retroinclination may be the result of a restraining effect of the orbicularis oris musculature on the crowns as the roots are carried forward by the prognathic mandible [2,4]. In contrast, the upper incisors and upper alveolar process in the prognathic patients were more proclined as compared with the normal controls. The upper incisors with the upper alveolar process may have been tipped labially by the tongue while the mandible was prognathic [4].

In this study, TPS analysis [10,11] was used to visualize transformations and to provide insight into the localization of anatomical deformations of the mandible in subjects with Class III malocclusion. The TPS function fits the differences in the positions of landmarks in one form relative to their positions in another [24]. This method models shape differences as a deformation between landmarks. The interpolation function used in spline analysis can be described by a physical metaphor in which the landmarks of one form located on an infinitely thin metal plate are deformed so that the height over each landmark is equal to the coordinates of the corresponding point in the other form [24]. The use of this spline does not imply that biological tissue behaves like metal sheets [25]. Instead, it is simply a convenient function that is able to express the differences in two configurations of landmarks as a continuous deformation.

The cranial base and midfacial complex may contribute to Class III discrepancies [26,27]. Enlow [1] indicated that Asian ethnic groups with a brachycephalic headform could have a relative retrusion of the nasomaxillary complex with a more anterior relative placement of the entire mandible, resulting in a greater tendency toward a Class III profile. Nevertheless, TPS analyses of the cranial base and the midfacial complex were not undertaken in the current study, and further exploration is warranted.

The Class III mandible revealed a longer mandibular body and a narrower ramus, allied with a larger mandibular angle, combined to form a longer mandibular total length with upward and forward extension of the ascending ramus and forward and downward extension of the mandibular symphysis. Typically, Class III malocclusion exhibits an altered molar occlusion with a horizontal discrepancy between the maxilla and mandible such that the mandible appears protrusive when the teeth are in occlusion. This may reflect an underlying skeletal discrepancy of maxillary deficiency and/or mandibular excess [28]. These problems can be clinically treated by various means.

Facial growth modification can be an effective method of resolving skeletal Class III jaw discrepancies with dentofacial orthopedic appliances in growing children. The ultimate treatment goal for developing skeletal Class III patients should not only be the correction of the jaw relationship and negative incisal overjet related to mesial occlusion at that stage, but also the stabilization of the intermaxillary skeletal and dental relationships resulting from orthopedic appliance treatment. Thus, close observation and follow-up of midfacial and mandibular growth during adolescence, particularly during the second or third stage of orthodontic treatment, is essential. Orthognathic surgery in conjunction with orthodontic treatment would be required for correction of this problem in adults [29].

In conclusion, this study showed that mandibular morphology differs between normal subjects and subjects with Class III malocclusion in our sample. The deformations in subjects with Class III malocclusion may represent a developmental elongation of the mandible anteroposteriorly, which leads to the appearance of a prognathic mandibular profile. Thus, a specific pattern of mandibular transformation is associated with Class III malocclusion and visualization of these deformations is feasible using TPS analysis.

Acknowledgments

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三級異常咬合者下顎幾何形態測量學分析

潘金芸[1]　周思婷[1]　張宏博[1,2]　劉保興[3]

[1]高雄醫學大學附設中和紀念醫院　齒顎矯正科

[2]高雄醫學大學口腔醫學院　牙醫學系

[3]國立成功大學　醫學工程研究所

本項研究的目的，在於使用幾何形態測量學，分析三級異常咬合者構成下顎外形的形變。對於 **100** 位的男、女成人與 **70** 位男、女孩三級異常咬合者，進行側面測顱 **X** 光片的分析，與配對的正常咬合對照組比較，樣本數男、女相同。**12** 項下顎標誌經數位板輸入電腦，藉由普氏疊合分析獲得下顎平均幾何圖形；然後，使用薄板仿樣分析測定三級異常咬合與正常咬合者下顎局部形態的差異所在。男、女成人與男、女孩兩組咬合者之間的下顎形態具有統計學上的顯著差異；薄板仿樣分析顯示三級異常咬合者下顎沿著髁突—頦前下點的軸向在髁突與上行枝部位以及下顎聯合前下部分有伸長的形變，伸長的情形成人更為明顯。三級異常咬合者的形變呈現下顎前後伸長的發育，導致下顎前突的側面外形。

關鍵詞：成人，小孩，三級異常咬合，下顎，形態測量分析

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通訊作者：張宏博醫師

高雄醫學大學附設中和紀念醫院齒顎矯正科

高雄市自由一路**100**號